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Request for grant of a patent

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1. Your Reference	P.7016 GBA
2. Patent application number *(The Patent Office will fill in this part)*	0223654.5 — 11 OCT 2002
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	NEW TRANSDUCERS LIMITED 37 Ixworth Place LONDON SW3 3QH G.B.
Patents ADP number *(if you know it)*	7283476007
If the applicant is a corporate body, give the country/state of its incorporation	G.B.
4. Title of the invention	ELECTROMAGNETIC ACTUATOR
5. Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	MAGUIRE BOSS 5 Crown Street St. Ives Cambridgeshire PE27 5EB G.B.
Patents ADP number *(if you know it)*	07188725001

	Country	Priority application number *(if you know it)*	Date of filing *(day/month/year)*
6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number			

	Number of earlier application	Date of filing *(day/month/year)*
7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application		

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body:)* *See note (d)*	Yes

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Continuation sheets of this form	
Description	13
Claims*(s)*	2
Abstract	
Drawing*(s)*	8 +8

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature Date: 09.10.02

Maguire Boss

MAGUIRE BOSS

12. Name and daytime telephone number of person to contact in the United Kingdom **JULIA GWILT** Tel: 01480 301588

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DUPLICATE

TITLE: ELECTROMAGNETIC ACTUATOR

DESCRIPTION

TECHNICAL FIELD

The invention relates to an electromagnetic actuator, in particular a moving coil actuator or transducer, e.g. for loudspeakers.

BACKGROUND ART

A known typical voice coil actuator comprises a coil assembly and a magnet assembly. The magnet assembly comprises inner and outer yokes of magnetic flux conductive material which together define an air gap in which the coil assembly is suspended for movement within the air gap. A radially

oriented magnet is sandwiched between the inner and outer yokes such that a first face of a first magnetic polarity is adjacent the inner yoke and a second face of a second opposite magnetic polarity is adjacent the outer yoke. For example, the use of a radially oriented magnet is shown in GB 670,027.

Such actuators may suffer from a large degree of flux leakage from the radial magnet. This makes the actuator unsuitable for some applications, particularly those in which the actuator is mounted close to a display used with a cathode ray tube. Furthermore, since a significant proportion of the magnetic flux is diverted from the air-gap, the magnet assembly size needs to be increased to ensure there is sufficient flux density in the air-gap to produce the necessary movement on the coil.

DISCLOSURE OF INVENTION

According to the invention, there is provided an actuator comprising a coil assembly and a magnet assembly which comprises inner and outer yokes of magnetic flux conductive material which together define an air gap in which the coil assembly is suspended for movement within the air gap, and a radially oriented magnet sandwiched between the inner and outer yokes such that a first face of a first magnetic polarity is adjacent the inner yoke and a second face of a second opposite magnetic polarity is adjacent the outer yoke,

characterised in that the magnet assembly comprises an axially oriented magnet which is mounted at the opposed end of the magnet assembly to the air gap.

The axially oriented magnet steers magnetic flux which is leaking from the radially oriented magnet towards the air gap so as to increase the magnetic flux density in the air gap. The axially oriented magnet may optimise the magnetic flux density in the air gap and may thus push the magnet towards an optimum operating point.

The axially oriented magnet may be generally ring or disc shaped. The axially oriented magnet may be mounted adjacent a face of the radially oriented magnet, the inner yoke and/or the outer yoke. A shield may be mounted adjacent the axially oriented magnet and may be attached to one or both of the inner and outer yokes. This provides a path for magnetic flux from the axially oriented magnet to flow to one of the yokes and may further reduce the flux leakage. The shield may be cup, disc or ring shaped and may be formed from steel.

The magnet assembly may comprise a second oriented magnet mounted at the opposed end of the radially oriented magnet, the inner yoke and/or the outer yoke to the first oriented magnet. The second oriented magnet may assist in reducing flux leakage from the magnet assembly.

The inner and/or outer yokes may have a cross-section which tapers to a point away from the air gap. The inner and outer yokes may be provided with chamfers adjacent the air gap to focus the magnetic field developed within the gap. The inner yoke may have a cross-sectional area which is larger than that of the outer yoke so that the volume of magnetic flux conductive material in both inner and outer yokes is approximately equal. The equal volumes may contribute to ensure that the flux density is similar in both yokes.

The actuator may be manufactured by adding the axially oriented magnet after the rest of the assembly is complete. The shield may be made by stamping and a recess may be formed in the outer yoke so that a corresponding protrusion on the shield may be located in the recess during manufacture.

The invention is diagrammatically illustrated, by way of example, in the accompanying drawings in which: -

Figures 1a and 1b are cross-sectional views of a prior art actuator showing the flux contours and the flux vectors of the magnetic field respectively;

Figures 2a and 2b are cross-sectional views of an actuator which is similar to that of Figure 1; the views showing the flux contours and the flux vectors of the magnetic field respectively;

Figures 3a and 3b are cross-sectional views of an actuator according to a first embodiment of the invention showing the flux contours and the flux vectors of the magnetic field respectively;

Figures 4a and 4b are cross-sectional views of an actuator according to a first embodiment of the invention showing the flux contours and the flux vectors of the magnetic field respectively;

Figure 5a is a graph of the modulus of the magnetic field strength Bmod against vertical position for the actuators of Figures 1a and 3a;

Figure 5b is a graph of the modulus of the magnetic field strength Bmod against vertical position for the actuators of Figures 2a and 4a;

Figures 6, 7 and 8 are a cross-sectional view of an actuator according to other embodiments of the invention showing the flux contours;

Figure 9 is a perspective ghost view of a magnet assembly of the actuator of Figure 8;

Figure 10 is a cross-section of a panel-form loudspeaker comprising the actuator of Figure 4a; and

Figure 11 is a cross-section of a cone loudspeaker comprising the actuator of Figure 4a.

In each of the embodiments, the actuator is symmetrical about a central axis 16.

Figures 1a and 1b show an actuator 1 which includes an inner yoke 2, an outer yoke 3, a cylindrical magnet structure 4 and an electrical current conductive coil 6 wound on a coil former 14. The inner yoke 2 and outer yoke 3 are constructed from magnetic flux conductive material (e.g. steel) and are generally cylindrical. The inner and outer yokes 2,3 are mounted coaxially and are both centred on a central axis of the actuator.

The magnet structure 4 is sandwiched between the inner yoke 2 and the outer yoke 3 which extend beyond the magnet structure 4 to define a gap 5 between the inner and outer yokes 2,3. The magnet is radially magnetised (oriented). Thus the magnet has a first face 7 of a first magnetic polarity e.g. N facing the inner yoke 2 and a second face 8 of a second, opposite magnetic polarity e.g. S facing the outer yoke 3. Flux lines 30 and flux vectors 32 show the flux leakage from the base of the magnet 4.

The inner yoke 2 has a cross-section which tapers to a point 26 adjacent a base 28 of the magnet and away from the air gap 5. The coil 6 is moveably suspended in the gap such that an electrical current in the coil 6 develops a Lorentz force on the coil 6 in a direction substantially normal to the

radial magnetic flux. The coil 6 is displaced in response to such magnetic force. There are various known means for suspending the coil 6 in the gap.

Figures 2a and 2b show an actuator 34 which is generally similar to that shown in Figures 1a and 1b. The length of the inner and outer yokes 38, 36 and magnet 40 of Figures 2a and 2b is shorter than those used in the actuator of Figures 1a and 1b. The magnet 40 is 20mm long. Flux lines 30 and flux vector 32 show the flux leakage from the base of the magnet 40.

Figures 3a and 3b show an actuator similar to that of Figures 1a and 1b in which a section of the inner yoke and the magnet has been cut away. As in the prior art embodiment, the inner yoke tapers away to a point 26 away from the air gap. However, the inner yoke is now in two pieces with the tapered tip section 50 being separated from the main section 48 of the inner yoke by a gap. The radially oriented magnet 46 is shorter in length than the corresponding magnet shown in Figures 1a and 1b.

An axially oriented magnet 42 is mounted adjacent the base 28 of the radially oriented magnet 46. A steel shield 44 is mounted to the base 52 of the axially oriented magnet 42 and supports the tip section 50 of the inner yoke. Both the axially oriented magnet 42 and the shield 44 are annular

rings. The axially oriented magnet 42 has a first face of a first magnetic polarity e.g. N facing the radially oriented magnet 46 and a second face of a second, opposite magnetic polarity e.g. S facing the shield 44. Thus, the magnetisation direction of the axially oriented magnet 42 is rotated by 90 degrees to the radially oriented magnet.

As shown in Figures 3a and 3b, the axially oriented magnet 42 steers the magnetic flux from the base 28 of the radially oriented magnet 46 towards the voice coil 6 in the air gap. Thus,. the axially oriented magnet 42 may be considered to be a steering magnet and although the main magnet has been shortened, there is no loss in magnetic field strength in the air gap.

Figures 4a and 4b show an actuator similar to that of Figures 2a and 2b in which an end of each of the inner and outer yokes 54, 56 and the radially oriented magnet 58 has been removed. The inner yoke 54 still tapers but is truncated and the radially oriented magnet 58 has a length of 15mm. An axially oriented ring magnet 42 is mounted adjacent the truncated end 62 of the inner yoke 54. The ring magnet 42 has a 15.2mm inner diameter and a 22mm outer diameter and is 4.5mm thick.

A shield 60 in the form of an annular cup comprising an annular steel ring is attached to the base of the axially

oriented ring magnet 42. The annular steel ring has a flange around its outer perimeter which attaches to the base of the outer yoke 56 and which defines a hollow chamber 61 at the base of the outer yoke 56 and radially oriented magnet 58. In this way the overall weight of the magnet may be reduced.

As in Figures 3a and 3b, the axially oriented magnet 42 steers the magnetic flux from the base 62 of the inner yoke 54 towards the air gap. The shield 60 provides a route or return path for the magnetic flux to pass from the ring magnet 42 to the outer yoke 56. This increases the steering of the magnetic field produced by the axially oriented magnet 42.

Values of the magnetic field strength Bl (Tm), the nominal force and Bl^2/Re (Ns/m) may be calculated or estimated for both actuators using standard techniques and are set out below. For the calculations, the coil 6 has 82 turns and 16ohm resistance:

	Nominal force (N)	estimated Bl (Tm)	Bl^2/Re (Ns/m)
Figure 2a embodiment	0.662	10.59	7.0
Figure 4a embodiment	0.638	10.21	6.51

Thus, both embodiments have comparable values of magnetic field strength and nominal force in the air gap.

In both the embodiments of Figures 3a and 4a, the overall length and weight of the actuator is approximately equal to

that of the corresponding actuator of Figures 1a and 2a. Although the length of the main radially oriented magnet has been reduced, a similar level of magnetic field strength is achieved at the drive point, i.e. in the air gap. In both embodiments the flux leakage is reduced and thus a more efficient actuator is provided.

In both of the Figure 3a and 4a embodiments, adjacent the air gap, the inner yoke is provided with chamfers 9,10 and the upper yoke is provided with chamfers 11,12 to focus the magnetic field developed by the radially oriented magnet within the gap. Thus, a more efficient magnet structure may be created. The angle of chamfering of upper and lower edges of the magnetic air gap 5 causes any flux vectors which are generated to be additive and focused in a radial direction.

The flux leakage of prior art transducers and transducers according to the invention is compared in Figures 5a and 5b. In each Figure, the modulus of the magnetic field strength (Bmod) is measured along a line which is parallel to and spaced at a distance of 50mm from the axis of the actuator. The line extends through the actuator and about 50mm in both directions outside the actuator. The thin lines 64, 66 show the value of Bmod for the unshielded transducers and the thick lines 68, 70 the value for the transducers according to the present invention.

In both Figures 5a and 5b, the magnetic field is more constant for the transducers according to the present invention showing that there is a significant reduction in the flux leakage. The stray field which produces the leakage is approximately halved in strength. However, there is a small reduction in the overall magnetic field strength.

The actuator shown in Figure 6 is similar to that of Figures 4a and 4b except that the axially oriented magnet 74 is in the form of a disc magnet rather than an annular ring. The shield 72 is in the form of a steel cup and the inner yoke 76 is generally cylindrical with chamfers 11,12 extending inwardly towards the air gap 5. Thus the shield 2 and the inner yoke 76 are not annular.

The actuator shown in Figure 7 is similar to that of Figure 6 with the addition of a second axially oriented magnet 78 mounted on the opposed face of the inner yoke 74 to the first axially oriented magnet 74. Both magnets 74,78 are disc magnets. The second magnet 78 further helps to reduce the stray field whereby the flux lines are substantially contained within the complete magnet assembly. The second magnet 78 is sometimes known as a bucking magnet.

Figures 8 and 9 show an actuator which is also similar to that of Figure 4a but which is made from simplified components having reduced machining requirements. The inner and outer

yokes 80,82 are both generally cylindrical with no chamfers or rounded edges. The shield 84 is an annular disc with a flange which is the same width as and is attached to the outer yoke 82. There are no rounded edges on the shield 84 and the volume of the chamber 86 defined by the shield 84 is reduced. The radially and axially oriented magnets 58,42 are the same as those used in Figure 4a. The radially oriented magnet 58 comprises four segments which are equally spaced around the inner yoke 80 and which form a generally cylindrical magnet.

The simplified design could be applied to the embodiment of Figure 6. By simplifying the design so that only simple turning of the metal parts is needed manufacturing complexity and cost may be reduced. The simplified design has the same magnetic strength and force in the air gap as the unshielded embodiment of Figure 2a but a 35% reduction in the radially oriented magnet and a 5% reduction in weight.

Figure 10 shows an application of the actuator of Figure 4a in a bending wave panel-form loudspeaker such as those taught in WO 97/09842 and known as distributed mode loudspeakers. The loudspeaker comprises an acoustic radiator in the form of a panel 21 which is mechanically connected to the coil former 14 through a coupling ring 17. The panel 21 is supported in an enclosure 24. The outer yoke 56 is attached to a rear face of the enclosure 24 whereby the enclosure also

supports the actuator. A resilient suspension 15 is attached to the inner yoke 54 and the coil former 14 to suspend the coil 6 in its zero current bias position. The actuator axis 16 is marked.

Figure 11 shows an application of the actuator of Figure 4a in a pistonic cone loudspeaker. The loudspeaker includes an acoustic radiator in the form of a cone 19 which is mechanically connected to the coil 6 via the coil former 14. The cone 19 is supported in a chassis 18 by a resilient surround suspension 20. The actuator is also supported on the chassis 18 by attaching the outer yoke 56 to a rear face of the chassis. A resilient expandable suspension, known as a spider 22 is attached to both the chassis 18 and the coil former 14 to suspend the coil 6 in its zero current bias position. The arrangement of the cone and both resilient suspensions are well known.

CLAIMS

1. An actuator comprising a coil assembly and a magnet assembly which comprises inner and outer yokes of magnetic flux conductive material which together define an air gap in which the coil assembly is suspended for movement within the air gap, and a radially oriented magnet sandwiched between the inner and outer yokes such that a first face of a first magnetic polarity is adjacent the inner yoke and a second face of a second opposite magnetic polarity is adjacent the outer yoke, characterised in that the magnet assembly comprises an axially oriented magnet which is mounted at the opposed end of the magnet assembly to the air gap.

2. An actuator according to claim 1, wherein the axially oriented magnet is mounted to a face of the radially oriented magnet.

3. An actuator according to claim 1, wherein the axially oriented magnet is mounted to a face of the inner yoke.

4. An actuator according to any one of claims 1 to 3, comprising a shield mounted to the axially oriented magnet and to at least one of the inner and outer yokes to provide a path for magnetic flux to flow from the axially oriented magnet to the at least one yoke.

5. An actuator according to claim 5, wherein the shield is cup shaped.

6. An actuator according to any preceding claim, comprising a second axially oriented magnet mounted at the opposed end of magnet assembly to the first axially oriented magnet.

7. An actuator according to any preceding claim, wherein the inner yoke has a cross-section which tapers away from the air gap.

8. An actuator according to any preceding claim, wherein the inner and outer yokes are provided with chamfers adjacent the air gap to focus the magnetic field developed within the gap.

9. An actuator according to any preceding claim, wherein the inner yoke has a cross-sectional area which is larger than that of the outer yoke so that the volume of magnetic flux conductive material in both inner and outer yokes is approximately equal.

10. A loudspeaker comprising an acoustic radiator and an actuator according to any one of the preceding claims which is mounted to the acoustic radiator to drive it to produce an acoustic output.

11. An actuator as substantially hereinbefore described with reference to and as illustrated in the accompanying figures 3a to 9.

12. A loudspeaker as substantially hereinbefore described with reference to and as illustrated in the accompanying figures 10 and 11.

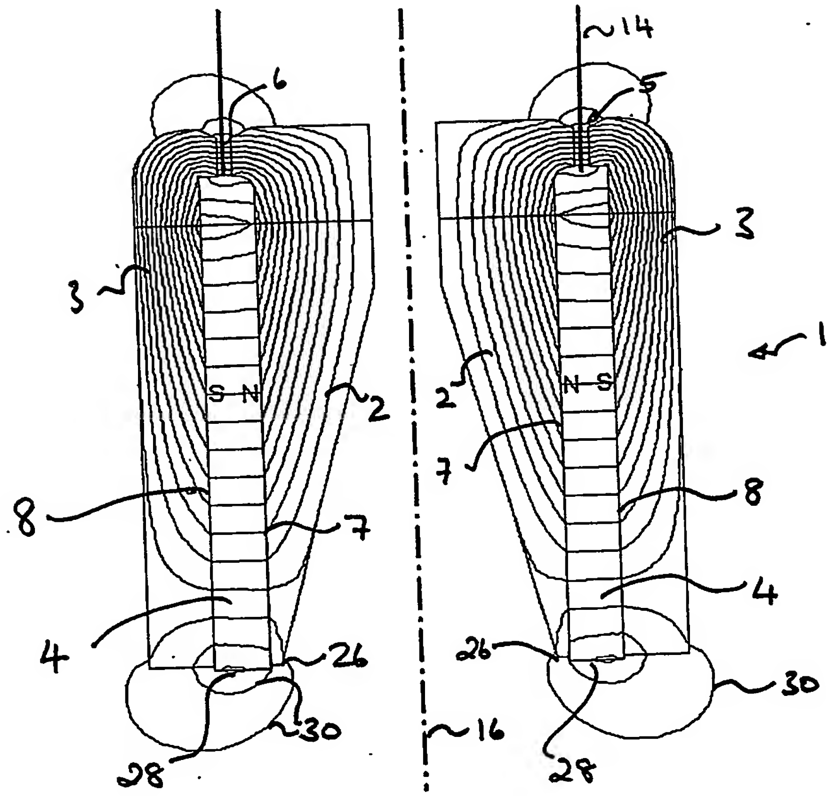

Fig 1a (Prior art)

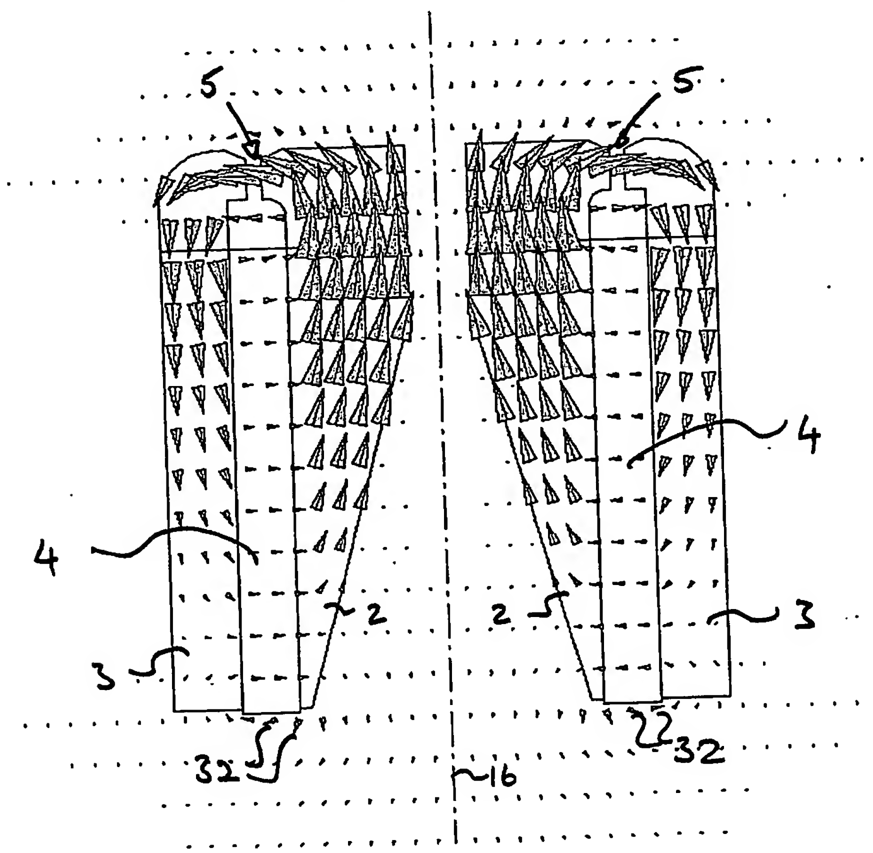

Fig 1b (Prior art)

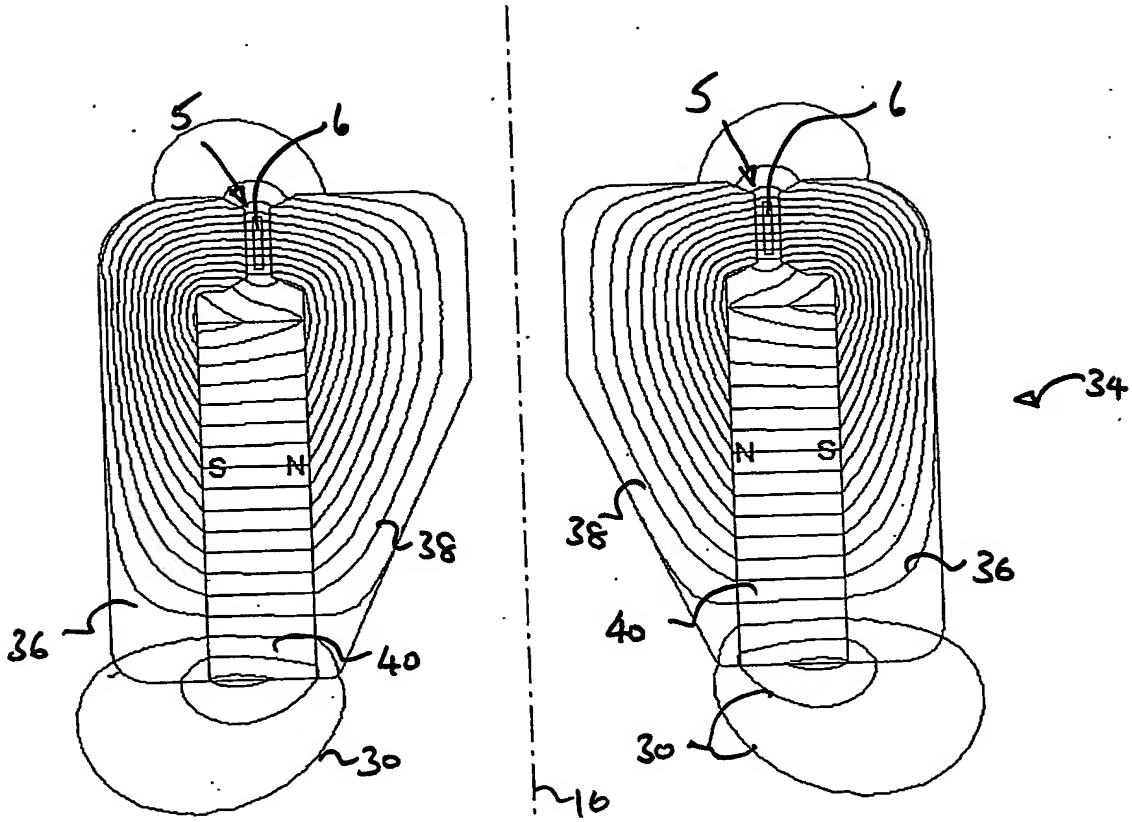

Fig 2a

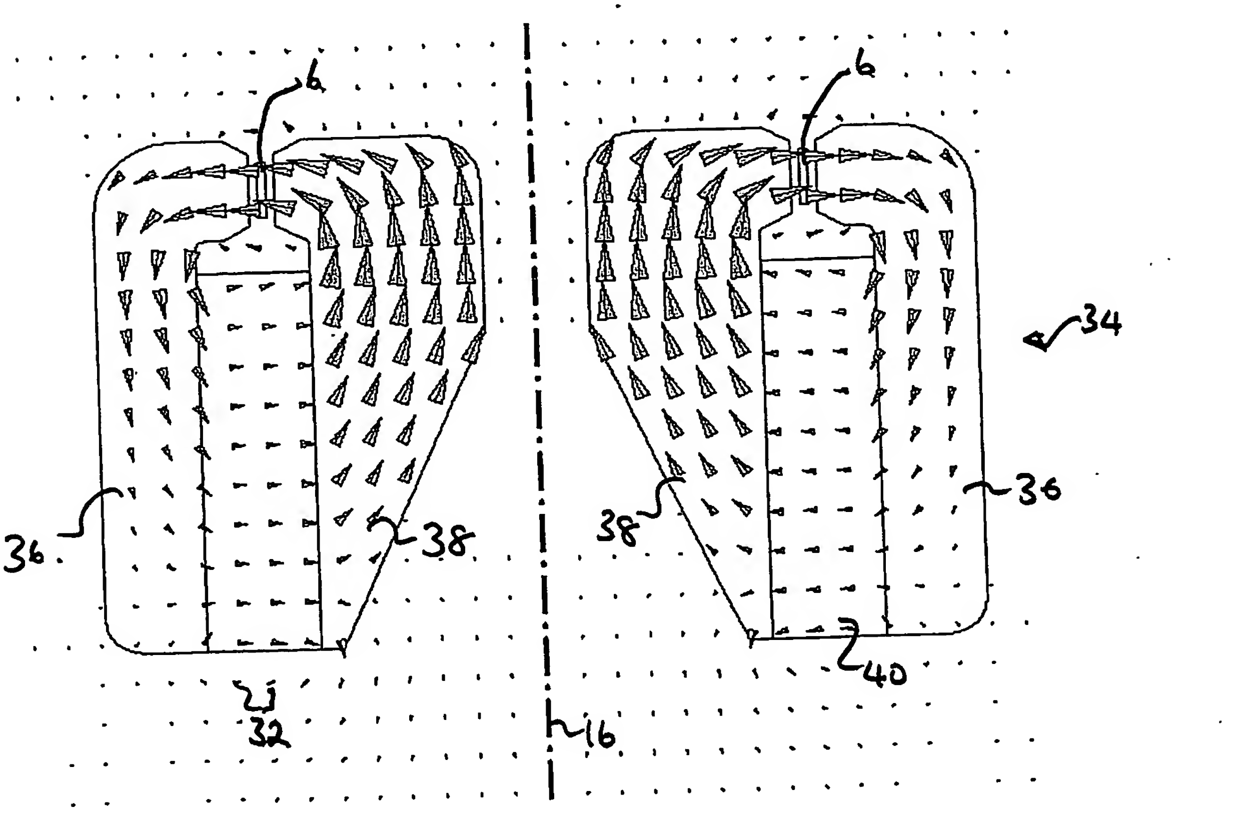

Fig 2b

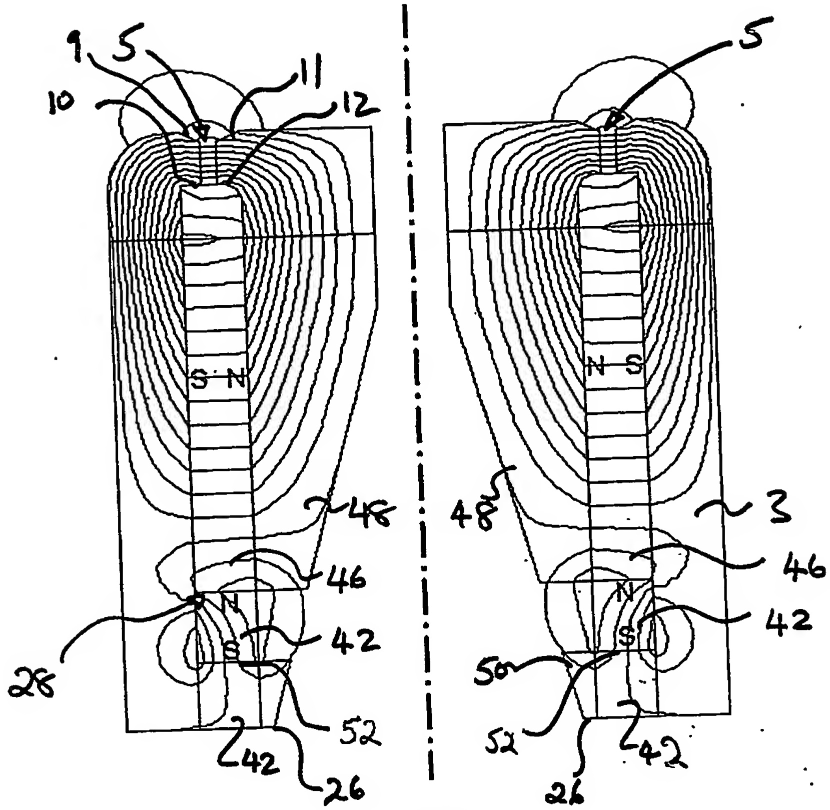
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Fig 3a

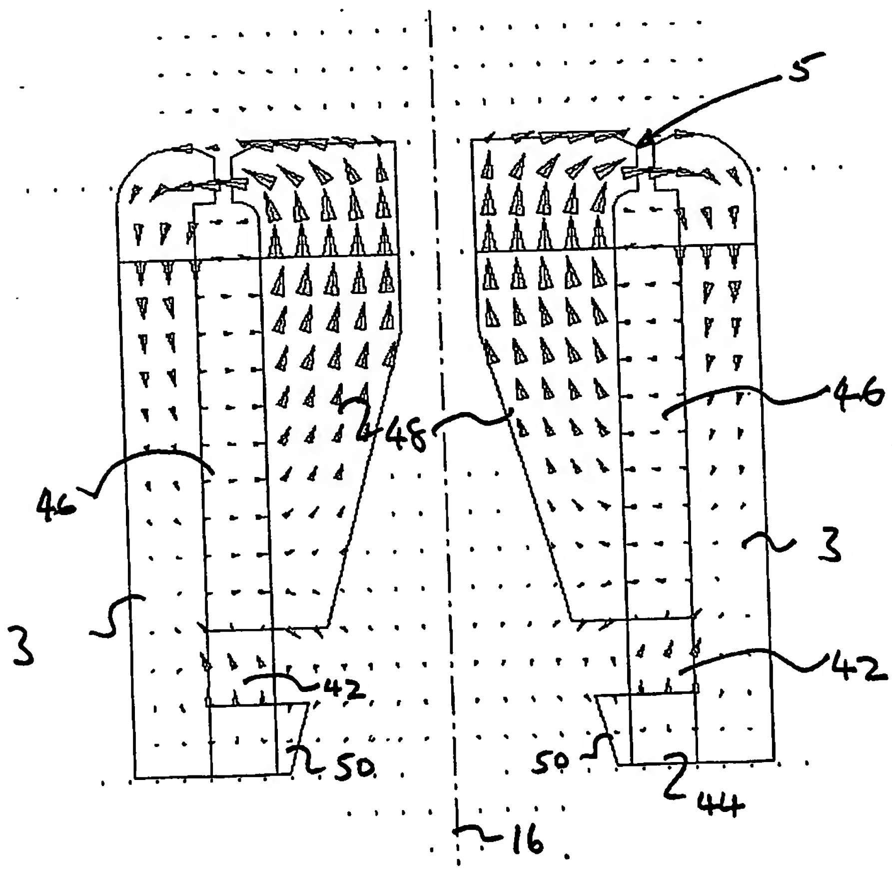
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Fig 3b

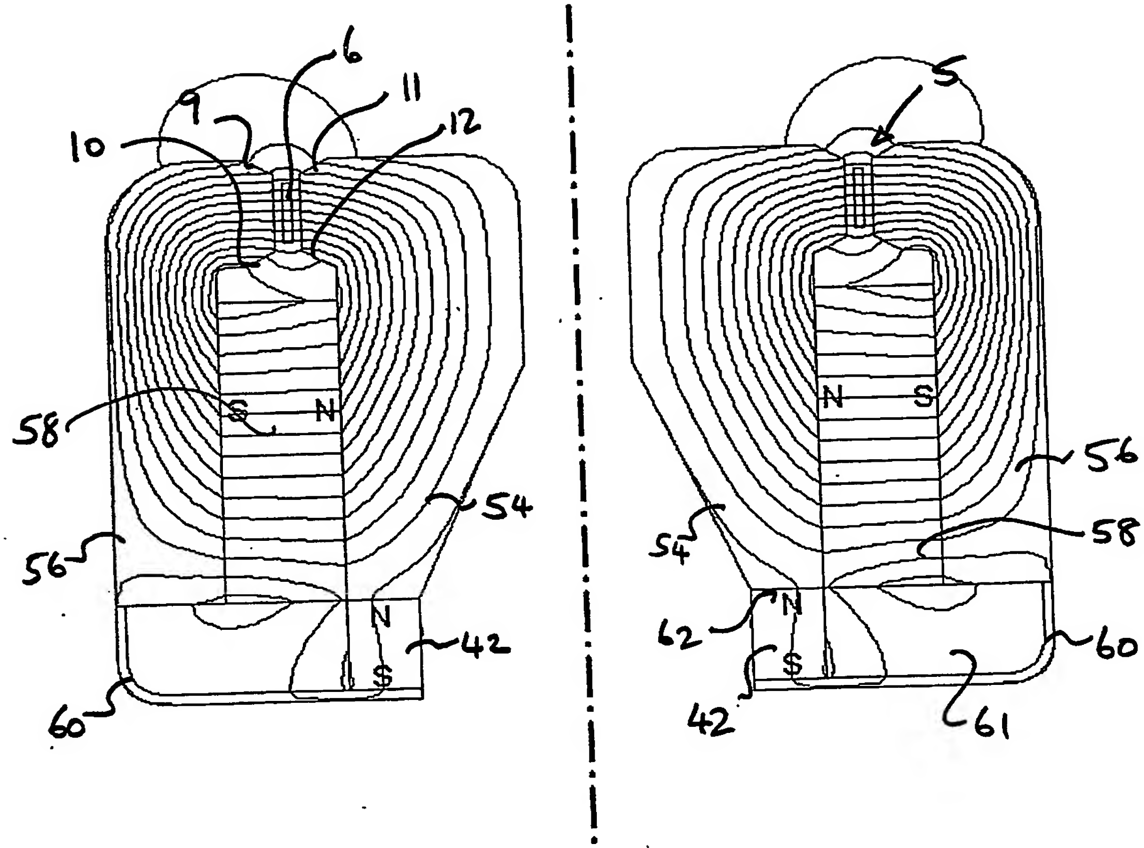

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Fig 4a

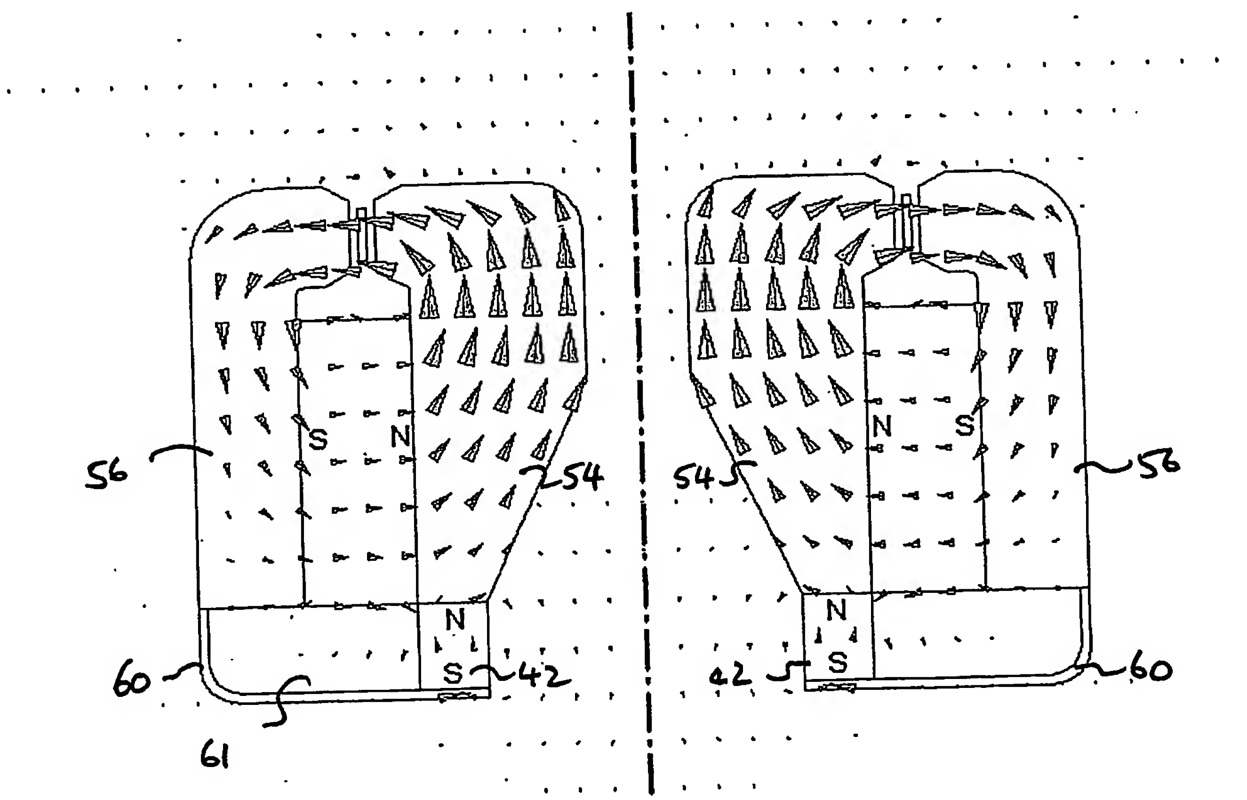

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Fig 4b

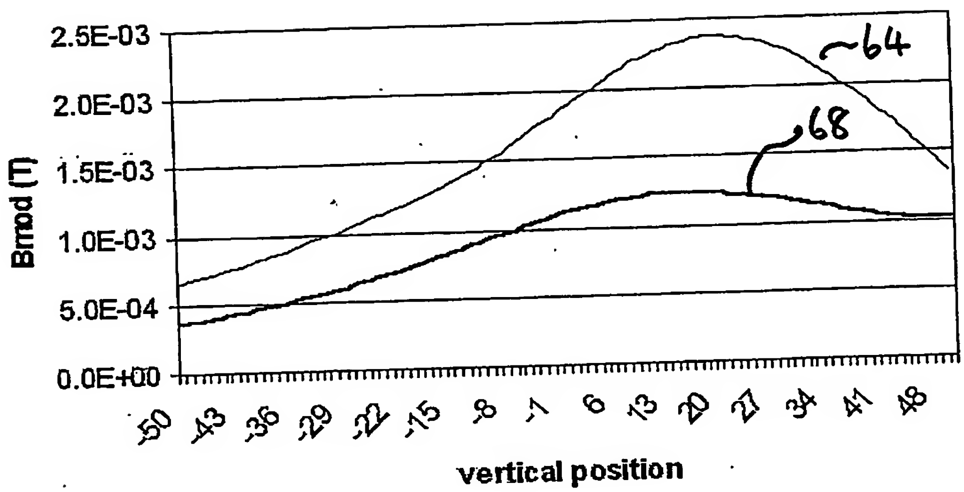

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Fig 5a

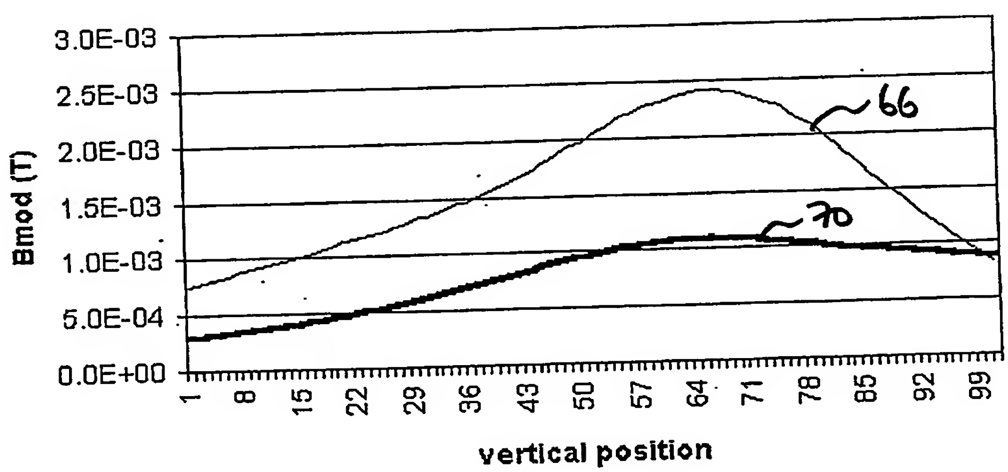

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Fig 5b

Fig 6

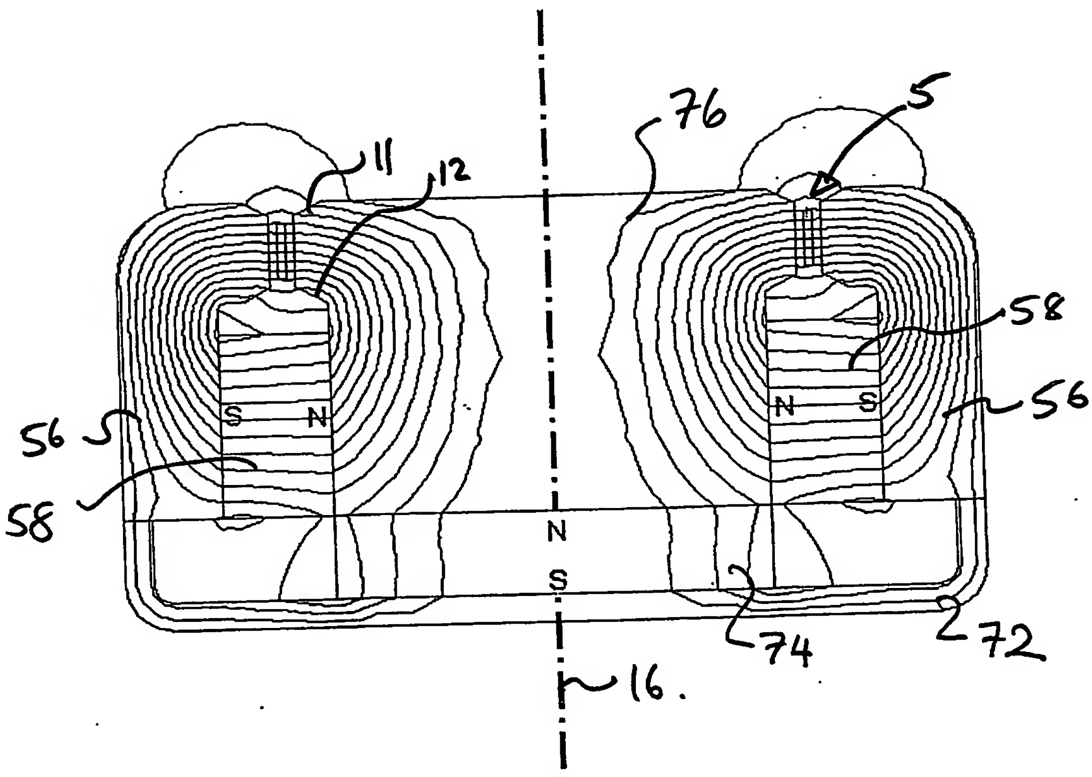


Fig 7

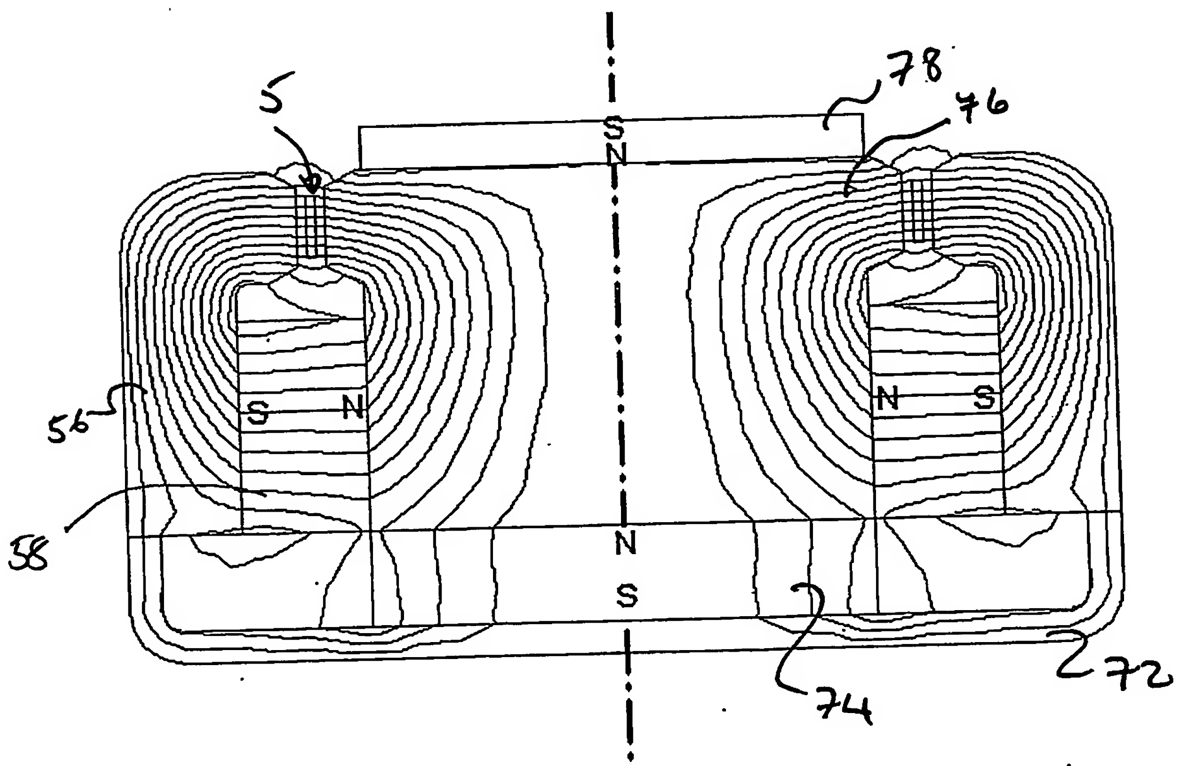
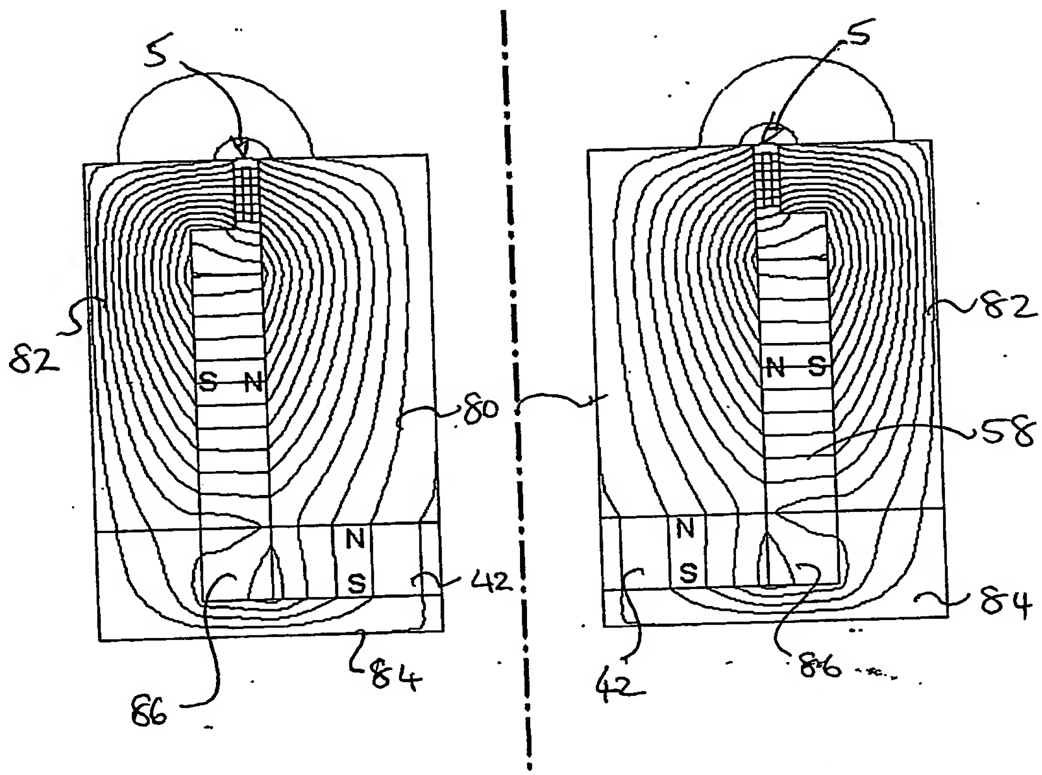


Fig 8



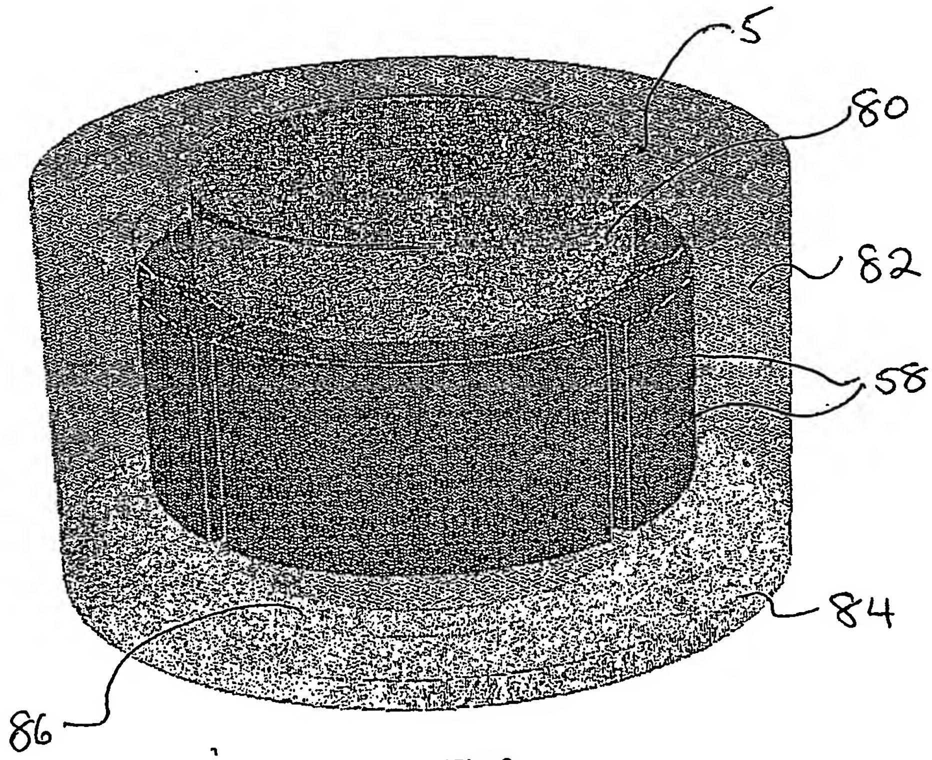


Fig 9

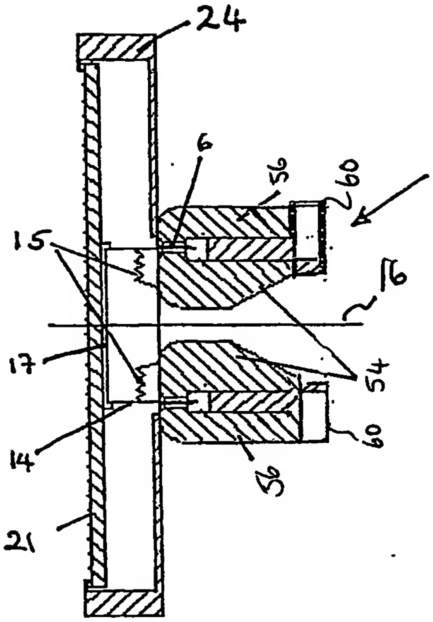

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FIG 10

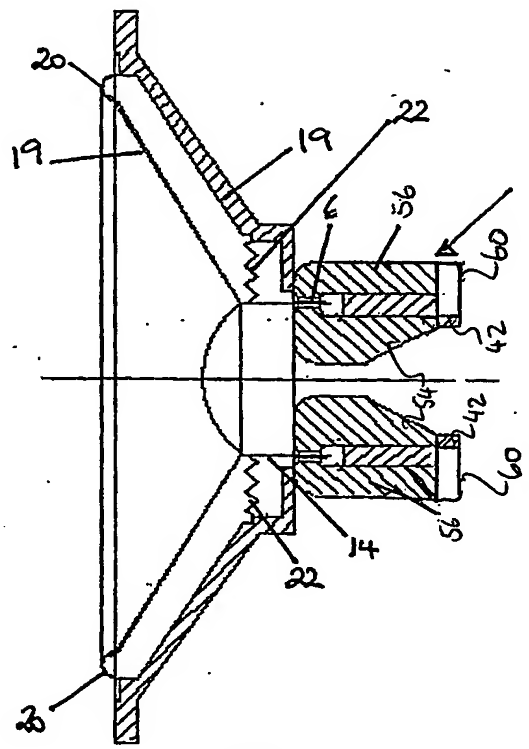
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FIG 11